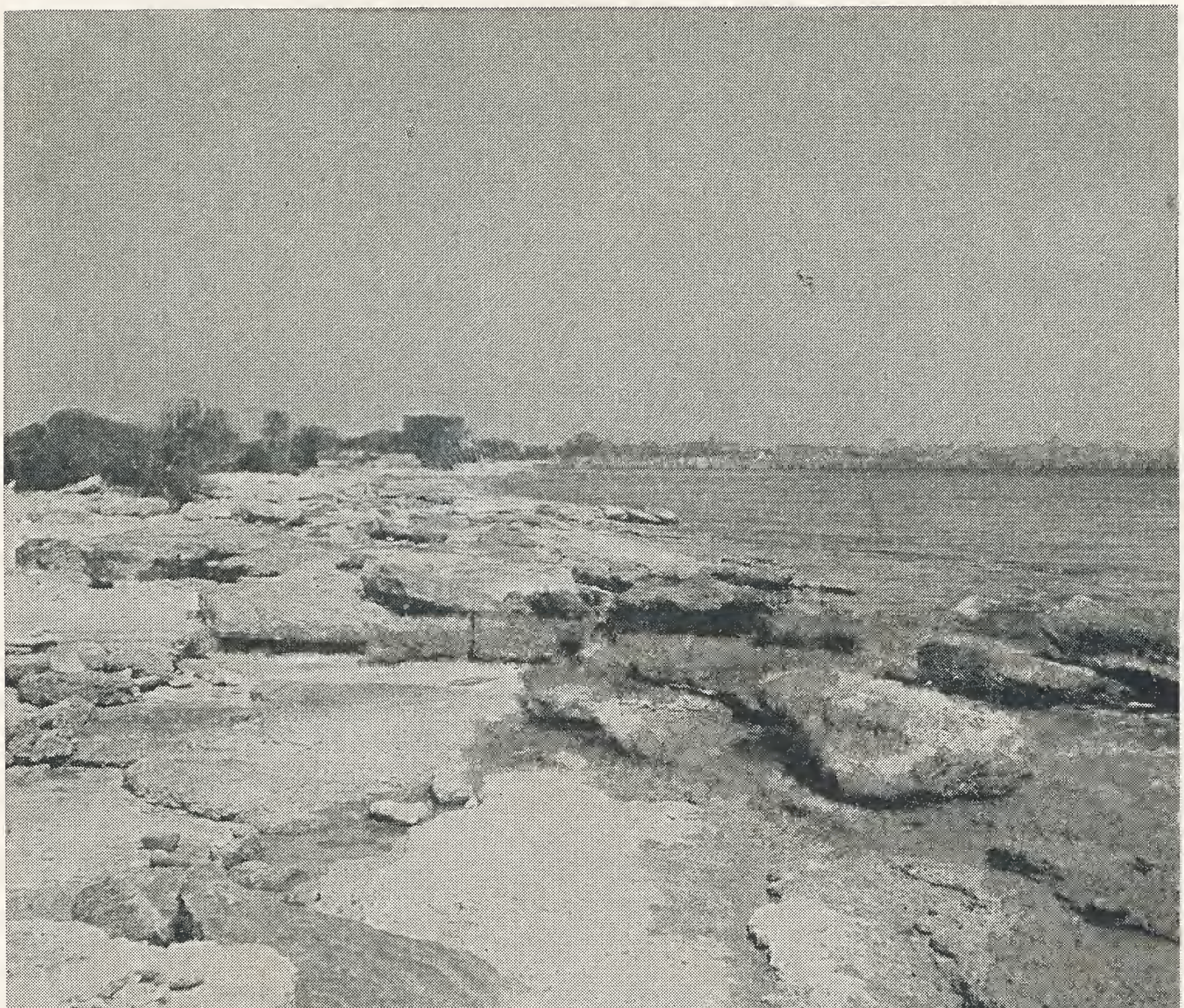
Schakels

THE NETHERLANDS ANTILLES



A SURVEY OF THE GEOLOGY OF THE LEEWARD ISLANDS

PUBLISHED BY THE NETHERLANDS MINISTRY OF OVERSEAS AFFAIRS, PLEIN, THE HAGUE

VOLUME 1959 NA 29

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Cover picture:
Playa Lechi, on the leeside of Bonaire. In the background to the right the Capital Kralendijk. The beach-gravel, composed of coral fragments, is cemented to a firm limestone. WOSUNA

Preface

In the year 1930 a group of students visited Curaçao for a geological investigation of the three Leeward Islands, under the supervision of their unforgettable tutor Professor L. M. R. Rutten.

A totally new world was opened up to them.

The Islands are fascinating and most students came under the spell of this area. Twenty-six years later Mr. P. H. de Buisonjé left Holland to do new geological research work, together with Dr. J. I. S. Zonneveld and the undersigned.

How he too was fascinated you can learn from the lectures on the geology of the Islands collected in this paper.

I hope they will illustrate how interesting these Islands are from a geological point of view.

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Introduction

It is a well-known fact that the three Leeward Islands Aruba, Curaçao and Bonaire are the trading centre of the Caribbean. It is less known that the Islands owe their importance to their natural geological structure.

The Leeward Islands have magnificent natural harbours, whereas in general the near-by continent has no such excellent harbours.

Before we look at Aruba, Curaçao and Bonaire from a geological point of view, let us first make some geographical remarks.

The Islands are situated between 12° and 13° Northern latitude and between 68° and 70° Western longitude, so in the tropics and quite close to the northern part of the continent of Venezuela. Weather permitting you can even see from Curaçao the steep coast of South America! It is striking that the Islands are situated on a line running East to West, while the longitudinal axis of each Island nearly always makes an angle of about 45° with this line.

On the northeast side of the Islands runs a strong, heavy surf in consequence of the prevailing easterly trade wind. On the other hand the southwestern side of the Islands is always the leeside, and here we notice a much weaker surf. If you want to swim safely in the warm water you have to be on this side of the Islands. It is also on this side that the important harbours are situated. All ships avoid the dangerous northeast coasts.

In 1956 geological research on the Leeward Islands was carried out on behalf of the Government of the Dutch Antilles, assisted by the Stichting Wetenschappelijk Onderzoek Suriname en de Nederlandsche Antillen, (WOSUNA) (Society for Scientific Research in Surinam and the Netherlands Antilles). However, many lengthy publications existed already on the geology of these Islands and so you will ask yourself what is the use of new research if so much is known already?

The answer is that geology is a relatively young science, the research methods developed quickly and after some time new research is certainly justified. Besides, the previous publications dealt principally with the older formations whereas little attention was paid to the geologically young reef limestone found elevated above sea level on the Islands. Moreover it was obvious that there was no consensus of opinion about the geological history of this reef limestone.

In 1956 new researches were carried out to obtain fresh information; at the same time efforts were made to reconcile contradictory opinions. This research concerned Aruba and Curaçao as well as Bonaire, because these three Islands have great geological affinities, especially as regards the young reef limestones. From another point of view, too, our Islands are geologically very interesting: they are situated in a tectonically restless territory, that is, on a part of the earth's crust where important movements took place a short time ago and are even taking place to day.

Similiar powerful mountain building movements created for instance the Andes, the Rocky Mountains, the steep Venezuelan coastal range and the Antillean Island ranges. The same movement, causing the strong folding and elevating of the earlier formations, is also responsible for the development of the highest hills of the three Islands.

Although the Islands were raised above sea level during this strong movement, (approx. 60 million years ago) they were several times completely or almost completely submerged after this first movement. Nevertheless we may take this first rise above sea level as the birth of the Islands as we know them to-day, be it in a very different shape. During the last submergence of the Islands, coral limestones were deposited on top of the earlier, folded, formations. After that, these reef limestones were elevated. And these very reef limestones have to-day become of great geological importance. Therefore we are trying to get as many details about the recent reefs as possible. But you know how dangerous a living coral reef is to shipping; it grows under the level of the sea, sometimes only just above low-tide level. So to study living reefs and to collect details about the erosion products and the limestone formed by these reefs, we should have to work under water, which gives rise to great difficulties. Where can we study them better than on the Leeward Islands, where these limestones are found above sea level and are accessible to the geologist?

So you see that the situation of the A.B.C. Islands, together with the geological details is very interesting to a geologist. The accompanying photographs will show you the beautiful scenery of the Leeward Islands. But how does a geologist look at these Islands?

First we shall have to amplify the notion that a geologist is somebody who strikes rocks with a hammer and looks at the bits and pieces through a magnifying glass! Of course, a geologist will never set out without these useful instruments, but there is more to it. For instance, he will always carry with him a compass, not chiefly to find his way (for this he has got his maps) but to fix on his map the position of the different layers. He also needs this compass to take orientated stone samples. Sometimes it is possible to determine, at home in the laboratory, a general stream direction in a sample. And if we know, too, how the samples were orientated in the field, we know that at the time a stream came from a certain direction.

Of course a rucksack, labels and a number-book are indispensable. Later the collected samples have to be examined in the laboratory. A camera, too, is needed, sometimes two, one for colour pictures and one for black-and-white photographs.

There is one very important thing the geologist of a few decades ago did not know, namely aerial photography. Aerial photographs are made from a plane with a special camera, so that every spot in the field will appear in at least two photos. This enables the geologist to look stereoscopically at every spot on the photograph. You can see perspective in the photographs and you can study beforehand the situation of the different rock layers, investigate their thickness and see if they have been folded, to which side they are dipping, etc., etc. Moreover, these vertically taken photographs will sometimes give much better information, because hillocks and bushes hinder the view when you are on the ground. On the other hand these very bushes may in the aerial photographs give a better understanding of the geology of the region in question. Slight differences in the vegetation of two geologically different formations are considerably clearer in an aerial photograph than on the ground.

But of course an aerial photo remains only an aid to the field geologist; he will always have to do field work in order to determine what kind of rocks are to be found in different places and how conditions are in detail.

Nevertheless it is useful to point out the fact how many interesting geological things you can see from an aircraft!

Approaching Curaçao by air the first thing that strikes you is the shape of the inland bays, like Schottegat, St. Joris Bay, Sta. Martha Bay, etc. All these inland bays are situated within the coastline itself and have a narrow junction canal to the sea. The second striking thing is the terraced northeast side of the Islands.

The airport of Curaçao as well as that of Aruba and Bonaire was constructed on the lowest of these terraces.

Along the coasts of the Islands the beautiful reef growth shows to full advantage. From the plane we can see the beautiful colour variations of deep-green patches where the coral colonies grow, contrasting with the light-green surroundings, where the bottom consists of limesand, and all these colours passing to deep-blue as the sea deepens.

It is precisely these minute coral polyps that have assisted in giving the Leeward Islands their present shape by their capacity to precipitate lime out of sea water.

Approaching the Islands by sea, we will get a quite different impression. For a while we are following a coastal fringe, mostly consisting of walls of whitened coral skeletons thrown up by the surf and immediately behind these walls in several places we see rather high limestone hills.

Entering, for instance, the harbour of Curaçao, the Schottegat, via the narrow junction canal, we can see that these limestone hills are mainly situated on the verge of the Island and consist of limestone layers, dipping seaward. The interior is composed of an undulating landscape, situated much lower, so the comparison with a hollow molar was made.

If we wish to learn about the geological structure of the A.B.C. Islands and how the present scenery originated, we will have to pass in review, shortly, the geological history of the Islands.

The earliest rocks of the three Leeward Islands are mainly of volcanic origin: lavas and tuffs, deposited under sea level. After the deposition of these volcanic materials, some gravels, sands, some lime and gravel stones were deposited on top of the preceding ones.

This entire formation was folded intensively; moreover, mobile substances, called magma, penetrated into these folded layers. Herewith the history of these territories as islands began, since it is evident that the level of the islands was greatly raised during this process of folding. Immediately after the elevation erosion started on the parts above sea level. Because Aruba was most strongly folded and elevated, it was subject to the strongest erosion. On Aruba many of these magma products, congealed deep in the earth's crust, are now found at the surface.

It is a well-known fact that the earth's crust is not at all solid and unchangeable; and so, after the erosion period, the Islands were submerged twice again. Now the sea acts as a collecting basin for the erosion products loosened elsewhere. So during the submersion periods young sediments like limestones, clays, marls and sands were deposited on top of the earlier deposits. And especially the sediments of the most recent submersion period are of great importance to us.

The latest submersion took place during the Ice Age, about a million years ago, when large parts of Europe and a considerable part of the Netherlands were covered with a thick cap of land ice. At that time the climate of the Netherlands was very uncomfortable, whereas the sea, covering great parts of the Leeward Islands, was warm, so that extensive reef growth was possible in the shallow sea along the coasts of the Islands. Afterwards several periods of vertical movements followed (or fall of the level of the sea, perhaps both) and the reef growth continued during these movements. Each standstill of the sea level created a more or less horizontal terrace. There has even been a period during which the sea level was 20 m. below the present level.

Meanwhile erosion had started already, and as a result the highest parts of the limestone cap were the first to disappear. Then the mainly volcanic rocks, lying under these limestones, came to the surface.

These volcanic products are much less resistant to erosion than the limestone capping them, and a widely ramified valley system was cut out in these volcanic products. Only at one point could the small streams excavating these valley systems cut through the hard limestone rim of the Islands. These rims came above sea level only a short time ago and were higher than the central parts.

The level of the sea rose about 20 m. and thus the valley systems formed in the centre were drowned.

In this way the widely ramified inland bays, connected with the open sea by a narrow junction canal, were formed.

Nowadays these drowned valleys are the natural harbours and constitute the source of the economic prosperity of the A.B.C. Islands.

Curaçao

Was Curaçao formed on a kind of mushroom-shaped rock, at the risk of breaking at the narrowest point of the stalk under the level of the sea, if all its inhabitants were to stand in one place at the edge of the Island? We, geologists, were often asked this question and we can immediately reassure everybody: Curaçao does not rest on a small stalk but on a solid base, getting wider as the depth of the sea increases. Yet the question is not quite absurd, and to make this clear we shall give a short survey of the geological history and the structure of the Island.

Seen as a whole, Curaçao has the shape of a halter, or of the figure 8 if you like, that is an oblong shape with a narrow part right in the middle. The longitudinal axis of the Island is in the direction Northwest to Southeast, and the prevailing rather strong, easterly trade wind causes a strong surf all along the Northeast coast of the Island.

On the Southwest side we find a much weaker surf, so here it is possible to enjoy a swim in the bays and along the beaches.

Owing to irregular rainfall the vegetation is rather poor and consists chiefly of cacti and thornbushes. It is true that the annual rainfall is about 60 cm., but this rainfall is rather irregular. Besides most formations of Curaçao are not capable of taking in this rainwater and immediately after a rainfall this precious fresh water runs to the sea.

However, the conditions of the earth's crust has not always been like this, our earth consists least of all of dead or invariable rocks. Thus, volcanism, folding, fracturing and elevation, formation of erosion products from parts elevated above sea level, and at the same time deposition under sea level of the erosion products, and the growth of coral reefs have all contributed towards giving Curaçao its present shape.

Now you must not think that such folding elevation or submersion are catastrophic events.

These phenomena nearly always progress very slowly and one does not notice them within a lifetime.

The earliest rocks of Curaçao consist of volcanic products, deposited for the greater part under sea level. These lavas and tuffs were deposited some 70 million years ago by volcanoes then found in the neighbourhood of our present Curaçao. Practically the whole centre of the large southeastern part of Curaçao is taken up by these lavas and tuffs.

Nearly everyone on the Island knows these rocks under the collective name of diabase. The erosion products of this diabase form the only natural fresh water reservoir.

Willemstad, the capital, is mainly supplied with water distilled from sea water. The more distant country houses and estates try to provide for their supply of fresh water by pumping up rainwater out of the diabase gravel. For that reason little mills are in operation in many places night and day, driven by the trade wind.

As a result of the rapid erosion, the diabase scenery generally attains an altitude of only a few score meters above sea level and forms a sligthly undulating, hilly landscape.

The formations in northwestern Curaçao which geologically are only a little younger, for instance in the surroundings of the Knip-Estate, are a sharp contrast to this. These formations contain a large quantity of quartz, a mineral much more resistant to erosion than the diabase. Alle summits, for instance the "Christoffelberg", the highest hill of Curaçao, with a height of 372 m, consist of these resistant rocks.

After a slight folding, the former formations rose partly above sea level and along the shores of these small islands, reefs could develop. But these reefs were quite different from the reefs around the Island, as they are at present. They were not formed by corals, but by queer shells, bivalves, of which one valve could grow into a long cup, whereas the other valve formed a kind of cover.

These islands only existed for a short time, the whole territory vanished below the sea and a layer more than a thousand metres thick and consisting of erosion products such as gravel, sand and clay, was deposited on top of the older formations. Of this thick deposit we can nowadays find the remains in Central Curaçao, i.e. in the narrow part of the Island.

Particularly striking is the fact that these gravels, sands and clays do not for the greater part originate from Curaçao itself. At that time a vast continent must have been situated in the vicinity of what is now Curaçao, a continent of which not a trace can be found back to-day!

Now we are coming to an important event in the history of the "Island": the older formations were subjected to a powerful mountain building movement and all the older formations of lavas, tuffs, gravel, sands and clays were not only folded but also elevated above sea level.

During this birth of Curaçao, magma penetrated into fractures and crevices of the folded formations, coming upwards from the depth. To these penetrating materials also belong a few veins containing copper ore. Unfortunately the quantity of copper ore is far too small to consider the possibility of exploitation. Someone has even said in jest that, when a geologist took a sample for his museum, the copper vein was exhausted!

To us it is of much more importance that these folded and elevated strata are the framework of Curaçao.

Especially northwestern and southeastern Curaçao were pushed up high, while the narrow central part stayed somewhat behind. But the parts elevated above sea level did not long remain stationary. erosion started immediately, denuding the oldest formations, especially the diabases in the northwestern and southeastern part of Curaçao. But this is not the end of the story. Curaçao disappeared entirely, or nearly entirely, under the sea twice after this first rise. Especially the second submersion is of great importance to us; during this second submergence, geologically only a short time ago (one million years!), when only a very small part of Curaçao, in the surroundings of the Christoffelberg, was above sea level the climate and other conditions were favourable for the proliferation of corals and seaweeds.

Big rivers were absent, the sea water was clear, the temperature was high and constant and so coral reefs could develop.

Now let us have a look at such a coral more closely. Perhaps you have got a piece of coral on your book-case or somewhere else.

Then you can see that such a coral does not consist of one organism only, but is composed of a tremendous number of small, separated individuals. Such a big colony developed from an originally free-swimming larva, having a size of only a few millimetres.

After swimming around freely for ten days or so, such a larva sinks to the bottom of the sea. If it comes down into a favourable

Coral-reef, elevated. Quarry Steenrijk, Curaçao. These minute organisms. building large colonies, are responsible for the formation of a large part of the island.

WOSUNA.

position, in a place where it can get continuous sunlight, the larva may grow into a big colony.

Anyone who has been skin-diving knows the silent and wonderful splendour of the undersea "gardens" of coral colonies. But a geologist does not only look at the coral colonies with respect to their beauty, he sees such a coral colony also as a kind of chemical factory. For each coral polyp has the capacity to precipitate lime, dissolved in sea water and to build a skeleton.

Some weeds too are working as such a small lime factory, and play an important part in the holding and luting of dead coral colonies, broken off and ground by the surf.

When Curaçao was only for a small part above sea level during the last great submergence, reefs were able to grow all around the small island. Where the water was too deep to allow the sunlight to penetrate, only broken-off pieces of coral came down.

The original rather small island started to rise, or the sealevel sank, which gives the same effect. Deeper parts were reached by the coral growth and in this way a cap of limestone was deposited all over the Island. The elevation of the Island above sealevel did not proceed at a slow and continuous rate; there were long periods during which the sea remained at the same level.

The horizontal extension of the reef limestones is characteristic of every period of constant sea level; as a result, we can find these beautiful, practically horizontal, terraces at various heights, especially on the northeastern side of Curaçao.

Though the growth of limestone took place under water, the erosional action of the climate started immediately on the limestone after emersion. At first the limestone was cemented together more solidly by dissolution, infiltration and evaporation but at last big parts of the limestone cap and especially the highest parts fell a victim to erosion.

Where the limestone disappeared, the older formations, much less resistant, were attacked by erosion with a better result.

Meanwhile the elevation of the Island continued, there has even been a period when Curaçao was about 20 m. higher than at present.

The central parts of northwestern and southeastern Curaçao had already disposed of their limestone caps, and small streams carried off the erosion products of the older formations much more quickly than those of the remaining limestone rims.

The small streams (or better "rooien" or "arroyos" for they only

The flat limestone terrace near the village of Lagoen, Curaçao. On the right a bay, a so-called "boca", in the terrace. Seaward dipping limestone formations in the foreground. The hills on the left are much older formations.

WOSUNA.

contain water after heavy rainfall) have a very peculiar pattern: namely a widely ramified gully system in the low-lying interior, while they managed to break through the hard and high limestone rim only at a single spot.

After this period of exceptionally low sea level the movement of the Island reversed: the sea level rose to about 6 m. above the present level.

The earlier gully systems were drowned: the sea penetrated through the limestone rim into the gully system of the interior via the narrow drainage canal. No longer had the rivulets to carry the erosion materials to the open sea, they could deposit their load di-

The natural source of the economic prosperity of Curaçao: The drowned valley system of the Schottegat, a natural harbour par excellence, with one of the greatest oil refineries in the world. WOSUNA.

rectly in the inland waters, formed by submergence. At the same time a new reef plateau developed along the coast of the Island and even along some places of the inland bays.

A fact not reffered to in the Introduction is that afterwards the sea level dropped about 6 m. with the result that this reef plateau is now 6 m. above sea level. But this drop of the sea level was not enough to drain all inland waters. In many places large inland waters were left, with here and there a natural wall of reef limestone and they communicate with the open sea via a narrow canal.

You cannot imagine a more beautiful natural harbour, so that the surroundings of the "Schottegat" have for many centuries been an important trading centre.

The minute coral polyps even played an active part in the defence of Curaçao against foreign powers, which in historical times tried to conquer the Island. Towards the end of the 17th century an immense fleet, sent by Louis XIV to capture Curaçao, was shipwrecked on the practically entirely submerged reef many miles long immediately east of Bonaire, namely the Aves Islands.

At the recently emerged so-called lower terrace on the northern side of Curaçao a magnificent airport has been constructed connecting the Island with all other parts of the world.

This lower terrace on which we find the airport, present all around the Island, has a vertical cliff in many places in which the strong surf excavated a solution notch many feet deep, extending horizontically underneath the limestone.

Sometimes this notch penetrates scores of feet horizontically underneath the lower terrace, hence the impression that Curaçao should rest on a narrow stalk!

This is certainly not true, and moreover, if this notch were to continue would strike against the kernel of older rocks. This limestone of course lies as a kind of big dome over the older formations. And because of their different structure these older rocks could never develop such a notch.

The elevated cliff coasts show very clearly that in former times Curaçao was deeply submerged under the sea.

Those landing at the Dr. Albert Plesman Airport near Hato can see very clearly two of those elevated terraces with their cliff coasts.

In these elevated cliff rims some of the surf notches remained and precisely on the ceiling of these old notches the original inhabitants of the Island made their rock drawings and at the foot of these notches we can find remains of primitive Indian pottery.

Worth mentioning also are the mysterious stalactite caves, which have their entrance in these elevated cliffs and which are often occupied by thousands of bats.

On the leeside of the Island the terrace structure is less evident and the limestone hills sloping down to the sea are much more striking. The entrance of the "Schottegat" at the Anna Bay cuts through such a seaward dipping limestone hill; "Fort Nassau" and the Transmitting Station have been built on the top of such a hill.

During the emersion, a long time ago, many animals must have

"Cueba di Raton di Noche", the "Cave of the Bats" in the neighbourhood of Hato, Curaçao. Calcareous sinter from rainwater seepage made this grotto into a beautiful stalactite cave.

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lived on one of the several limestone hills on the southwestern side of Curaçao, called "Tafelberg Santa Barbara".

There you can find deposits of phosphate, resulting from a chemical reaction between the "guano" (manure) and the limestone underneath.

The exploitation of this phosphate takes place in a big open pit. At present the Tafelberg Santa Barbara is the only place where profitable exploitation is possible, though phosphate deposits are known in other parts of Curaçao and the two neighbouring Leeward Islands.

The reason why there is no phosphate on the other flat-topped hill of Curaçao near St. Hieronymus, although it is of the same height, is the different origin of the limestone there.

This limestone cap did not rise above sea level as a solid mass, but originated as an immense limesand drift dune, afterwards cemented to a firm limestone. In other places, too, such "fossil" drift dunes were identified, some of them even of a geologically rather recent date. However, no dunes are found on Curaçao to-day. To find real dunes comparable with the "fossil" dunes we shall have to go to the neighbouring island of Aruba.

Aruba

The scenery of Aruba, the neighbouring-island to the west of Curaçao is dominated by a small conical hill, the Hooiberg. This hill with a height of 164 m., one of the highest of Aruba, stands by itself in a rather low and level territory.

Whoever has travelled to Aruba by air will have noticed several heaps of big stones lying scattered around the Hooiberg. These heaps of large boulders, when observed more closely, remind us of pre-historic gallery graves fallen to pieces.

As soon as you ask yourself the question: "How did these boulders get there and why is the Hooiberg standing there like a beautiful cone", you are getting interested in the geological history of the Island!

As we have seen, the base of Curaçao consists of strongly folded series of older formations of which the volcanic products as lavas and tuffs are the oldest.

These volcanic series which also occur in Aruba, are again the oldest we know, with this difference that here in Aruba they have changed a good deal. Especially they have been re-crystallized by the magma which penetrated during the folding. This fluid, mobile magma originally cooled down deep in the earth's crust, but the accompanying folding and elevation were much more powerful than in Curaçao.

As a result of the erosion, starting immediately after the elevation above sea level, a large part of the surrounding rock disappeared so that in Aruba this magmatic or igneous rock (solidified at a kilometre's depth) covers a large part of the area.

In general a geologist is not interested in isolated stones, nevertheless it is worth while looking at walls of natural rocks, since you will see them everywhere around small blocks of land in the surroundings of Paradera, northeast of Oranjestad, Aruba. In Curaçao such walls were built of limestone lumps, whereas in Aruba they were built of more rounded, granite-like rocks.

Natural limestone bridge, resulting from the action of the waves north east side of the Colorado Seroe, Aruba. WOSUNA.

These rocks consist of diorite, a rock related to granite. The igneous rocks at Aruba chiefly consist of this diorite.

The diorite, not very resistant to disintegration, shows a rather level scenery, here and there with rounded blocks which were a little more resistant to erosion. The larger ones are mostly found in great heaps as for instance near Santa Cruz, where the little church is hidden by enormous diorite blocks.

The rocks of the Hooiberg also belong to these magmatic igneous products. These rocks of the Hooiberg have a structure and composition different from the diorite and they are more resistant to erosion. So the Hooiberg is standing as a high top in the level diorite scenery.

Yet the geological histories of Curaçao and Aruba are related.

Diorite scenery of Aruba. A wall of diorite fragments, collected between the large, rounded boulders. On the right the Hooiberg (169 M). WOSUNA.

At Curaçao, for instance, some copper veins and some layers of igneous rocks related with the folding of the older formations are found.

In the same relation quartz levels are found in Aruba, containing gold, but only in small quantity. Since their discovery in 1824, these veins containing gold have occasionally been exploited.

Exploitation proved to be hardly if at all renumerative and so it could happen that afterwards the blocks brought up during the exploitation operations were used for other purposes.

Large quantities of this quartz were used to build a road and there will be few countries where gold ore is used as an underlayer for bitumen paving. Just as Curaçao after its first emergence above sea level, Aruba, too, was submerged twice entirely or almost entirely as a result of the folding and elevation. During the second of the submersions here, too, coral reefs could develop and when the Island emerged above sea level, a limestone cap had been laid on top of the older formations. There even was a period during which the sea level was 20 m below the present level. At that time rivulets were running towards the sea, but the lower parts of the drainage systems were filled with sea water as the level of the Island fell again about 25 m.

As a final phase of this irregular elevation, the Island rose for about 5 m., bringing reef limestone around the Island above sea level.

Yet a part of the former mouths of rivulets were still filled with sea water. The "Spanish Lagoon", a sea arm stretching inland for about 2 kilometres, is one of the best examples.

But there are no such extensive inland waters as in Curaçao.

The harbour of Aruba owes its existence to another phenomenon.

Aruba, situated with the long axis from northwest to southeast, has on the leeside, that is on the southwestern side, a reef rim of more than ten kilometres, running parallel to the coast proper for a distance of some hundreds of metres.

Inside this reef rim we find a lagoon with very quiet water.

In two places this lagoon has been made into a harbour by dredging. These harbours can accommodate big ships, and the ships moor to the lower terrace.

Especially on the northeastern side of Aruba, where the full force of the surf, whipped up by the easterly trade wind, beats the coast, the limestone terrace disappeared in several places and the older formations are showing up.

Where the limestone cliff coast is still present, we often see a deep notch where the limestone dissolved at wave level. There are places where this notch extends underneath the lower terrace (with a thickness of about 6 metres) for as much as a hundred metres.

If part of the ceiling collapses, a natural limestone bridge is formed, which even holds a truck!

If there is a hole at the back of the notch, the air, being compressed by the rolling waves, will try to escape through the limestone cap with a whistling sound.

Sometimes a jet of water follows, an unpleasant surprise when one is taking photos!

Elevated terraces are being found at different heights. Sometimes the notches, formerly made by the action of the waves, are still present as grottos.

Especially striking are the sand dunes of Aruba. In a few places, especially at the northwestern most extensive point of Aruba, we find drift dunes with a maximum height of 15 metres. These dunes consist of totally different sand grains as compared with normal dunes.

In Aruba these sand dunes are composed of limestone grains, or limesand and are the result of the growth of reefs along the shore together with the strong wave action. Broken off corals are ground down to sand grains and washed ashore.

From the shores this limesand is blown up to elongated sand dunes, lying exactly in the direction of the trade wind.

In Curaçao and Bonaire we also find such limesand dunes, be it in a completely different condition. For limesand may very rapidly be changed into firm sandstone, sometimes even within a few years!

Before we leave Aruba, we must call your attention to the fact that this small Island, only 175 sq. km, is well-known in geological literature. At the time of the description of the structure and composition of the rocks of the Hooiberg, these rocks were unknown in the rest of the world. For this reason we know such rocks nowadays in geological literature as "Hooibergites"!

Bonaire

It takes only a quarter of an hour to reach Bonaire by air. First we fly over a small island, called Klein-Bonaire, and a few minutes later touch down at the airport, which has been laid out only a few metres above sea level on the limestone terrace, directly south of Kralendijk, the capital of Bonaire.

Immediately after you have got off the plane, you can see the most important natural building material of the Island. In a border in front of the small, but very nice, reception and departure hall you may notice some beautiful corals, glittering in the sun.

The name "Kralendijk", formerly called: "Koralendijk" (Coral Dike) accentuates the importance of corals for the development of this part of the Island. Kralendijk has been built on a beach wall of dead coral colonies.

In Bonaire too the earliest rocks chiefly consist of volcanic products. Lavas and tuffs, deposited under sea level, predominate and alternate occasionally with layers of sandstone or limestone.

The birth of the Island took place when these rocks were folded and elevated. But after this first elevation, Bonaire disappeared a few times under the level of the sea.

During the various submersion periods new strata were deposited on top of the earlier ones. But the first rocks, mainly of volcanic origin, were more resistant than the younger ones, and today these earliest rocks still form the highest parts of Bonaire.

During the first submersion period after the above–mentioned folding and elevation, limestones and gravel beds were deposited on top of the earlier, mainly volcanic, formations.

Only a few small patches of these limestones and gravel deposits remained. But for a geologist they are sufficient to draw a surprising conclusion.

For in these gravel deposits we can find pebbles of granite and similar material. But in Bonaire native granitic rocks are entirely lacking. So the rivers, depositing these granitic pebbles, where Bonaire is now, must have had their drainage basin in an area with granitic rocks, somewhere in the vicinity of Bonaire. But today this continental area has completely vanished.

The affinity to Curaçao is apparent when we remember the conclusions with regard to the sediments of Central Curaçao. Here too elements are found which were derived from an unknown area, formerly situated in the neighbourhood of the present Island.

I could tell someone in Bonaire showing me some of these exotic pebbles without any hesitation that he picked them up at Soebi Blanco, a small spot in Bonaire, where these remarkable gravel deposits are found.

During the second submersion of the Island new sediments, like marls and limestones, were deposited. From these marls and limestones, too, only little is left, for their formation was followed by a long period of strong erosion.

The third submersion period, however, was very important again. During this time conditions were favourable for the proliferation of corals. The coral growth continued without interruption during the rise of the Island and a firm limestone deposit on top of all preceding formations was the result.

The emergence of the Island took place in several phases: short periods of vertical movement were followed by long periods when the level of the sea remained stationary. During each of these periods a cliff coast was cut out from the older rocks and at the same time, new coral reefs were growing out in the sea in the places where sunlight could penetrate to the sea bottem.

In this way a nearly horizontal reef flat, seperated from the higher parts of the Island by a vertical cliff, was formed. Going from Kralendijk along the main road to Rincon, the second largest town of Bonaire, you can notice several of these elevated terraces separated by vertical cliff walls.

The last chapter of the geological history of Bonaire shows a striking similarity to the youngest development of Curaçao. From a geological point of view Bonaire passed through a period during which the level of the sea was about 20 metres below today's only a short time ago.

Rivulets, having already a wide-spreading gully-system in the older rocks of the inland, managed to break through the recently emerged limestone rim only in a few spots.

Lake "Goto", Northwest Bonaire; The rising sealevel drowned a valley system. In the background the hill tops of the older, volcanic formations are visible. On either side of the junction canal limestone formations. The junction canal to this inland bay is closed by a beach wall of coral debris.

WOSUNA.

During the rise of the level of the sea, following this period of exceptionally low water level, the lower parts of the gully systems were drowned, thus forming large inland bays.

Slagbaai and Goto are examples of such inland waters; they are in communication with the open sea via a rather narrow canal, the former outlet of the drainage system through the limestone rim of the Island.

Finally the level of the sea fell about 5 metres, bringing a wide limestone terrace, extending all around the Island, above sea level.

This so-called "lower" terrace makes up the vast southeastern part of Bonaire and the whole of Klein-Bonaire.

Unfortunately the entrances to the inland waters forming such magnificent harbours at Curaçao, are closed at Bonaire by walls of coral debris.

Some parts of the very level lower terrace of southwestern Bonaire are just under sea level. These inundated areas are separated from the open sea by beach walls of dead coral colonies.

Evaporation of these extensive shallow seawater basins during the rainless, so-called "dry season", results in the formation of vast salt-layers. This salt is dug off with rakes and spades and transported by wheel barrow. In former days this salt was one of the most important products of the Island.

These wide shallow sea water pools provide an excellent breeding ground for the shy flamingo. This flamingo colony is the pride of the Island.

Bonaire has no real harbour. Right opposite to Kralendijk, lying on the leeside of Bonaire, the small island of Klein-Bonaire is situated. The sea between Kralendijk and Klein-Bonaire, lying at a distance of about 1.5 kilometres, is rather deep, a hundred metres.

So in order to make it possible for great ships to moor, it was sufficient to build a pier, perpendicular to the shore line, where the sea bottom has a steep slope.

To a geologist studying the elevated reef limestones it will be very instructive to look more closely at the living reefs around the Island. Today such an investigation is facilitated by the use of a mask, snorkel and fins.

More confirmed "land-lubbers" can look at the living reefs through the glass bottom of a boat especially designed for this purpose. So on our trip to Klein-Bonaire we were lying with our noses flat on the bottom of the boat: during the whole crossing!

In this way some centuries old cannon were discovered, the armament of a ship wrecked hundreds of years ago near the salt pans of southwestern Bonaire.

Now you may wonder: What is the connection between these cannon and geology? But a geologist is also interested in the rate at which corals grow. If we know the exact date of the shipwreck and the size of the corals growing on these cannon, we can make a rough estimate of the rate at which corals grow.

Just as on the other Leeward Islands, we find practically all around Bonaire the same lower-terrace consisting of reef limestone. Elevated cliffs, likewise consisting of reef limestone, are present in several places in the Island.

When in these cliffs the original notches made by the action of the waves are preserved we often find on the ceiling of these notches the rock drawings made by the Indians, the first inhabitants.

During the last emergence of Bonaire there were not always the same conditions along the shores. There have been times when the scenery was dominated by immense dunes. These high dunes were raised by the trade wind. The sand consisted of limestone grains, quite different from normal dune sands. Such limesand is rather quickly cemented to a firm limestone and the former dunes are preserved in the form of a large limestone cap.

Now we have come to the end of our short geological description of the Leeward Islands. It will be well to stress the fact that we must see the geological history of these Islands as a part of the whole! For these Islands originated simultaneously with the Andes Mountain Ranges and the Rocky Mountains. So the A.B.C. Islands are a small link in world-embracing mountain ranges!

"Seroes" and "rooien" on the A. B. C. Islands

What are "seroes" and what are "rooien"?

On the Leeward Islands every hill is called a "seroe". Most of these hills are not very high, but striking, because they are situated, more or less by themselves, in a low or level area.

But it is more difficult to explain the word "rooi". A "rooi" could be translated by "gully", for a "rooi" is the bed of a small stream, mostly dry. The rainfall on the A.B.C. Islands is very irregular: mostly short, rare, but heavy showers. During such showers the "rooien" change into wild torrents, which immediately drain off the precious fresh water to the sea.

But how did these "seroes" and "rooien" originate? To make this clear we have to remember that every rock above sea-level is constantly exposed to weathering. Solution and chemical weathering by rainwater and humic acids from the vegetation, disintegraton by temperature fluctuations and other mechanical forces are constantly wearing down our continents.

On the Leeward Islands, the wild torrents into which the "rooien" change during heavy showers, in their turn try to carry the loosened weathering products off to the sea.

No matter what kind of rocks, erosion is always proceeding.

But you will say this rock was already lying here in my childhood and those old buildings have been standing there for a thousand years or more. In geological history, one million years is only a short space of time, but those years are quite sufficient for big granite boulders to disintegrate by erosion to sand and clay. Of course not all rock disintegrates at the same speed. Granite for instance is more resistant to erosion than soft volcanic tuffs and that is how the highest tops of the A.B.C.-Islands originated.

The surrounding softer rocks were demolished more quickly than the more solid rocks of these tops. Let us take for instance the "Christoffelberg" in Curaçao:

When you climb this hill, you will find that the top consists of a solid and sharp material: a siliceous deposit (a chert), which geologists call radiolarite, because under a microscope these cherts were found to contain shells of minute organisms known as radiolaria.

Now there are various other siliceous rocks. But they have one thing in common: they disintegrate very slowly. This is evident in the Netherlands, too. The rivers, which played such an important part in the development of our country, transported the erosion products down here across a great distance. Yet they could not easily break down the siliceous rocks and everyone knows these materials as sand and gravel. If you take the trouble to examine them closely, you will surely find pieces of radiolarite in these gravels, usually of a beautiful red colour.

The rocks surrounding the "Christoffelberg" in Curaçao belong to what is known as the diabase: Now this word diabase is used somewhat loosely as a collective name for various volcanic deposits. This diabase, partly extrusive rocks, is of a different composition and is alternated by layers of volcanic tuffs. These tuffs are the consolidated ashes, ejected in enormous quantities by volcanoes in the surroundings of what is now Curaçao. These ashes settled down on the bottom of the sea and formed tuff layers.

Sometimes lava flows were injected between the tuffs or extruded as a sub-marine lava flow over the preceding deposits. These volcanic rocks, the oldest of the Islands, disintegrate very fast and form the lowest parts of Curaçao and Bonaire. Everywhere in the diabase area we notice a low and undulating scenery. The more solid parts of this area, being of varying composition, were more resistant to erosion and stick out as "seroes". The "rooien" preferred the lower parts, so usually the softer rocks. Sometimes disintegration proceeded deep into the earth. So to find a small piece of the original, not disintegrated rock, we have to climb the top of a "seroe". And often, even on these tops, we find a thin layer of red disintegration dust around the rocks.

When we are standing on the top of such a "seroe", it may be useful to look around at our ease. For there are places where we can see the "rooien" running neatly parallel and debouching into a larger one, at right angles to them.

This pattern is a result of the fact that during the folding and elevation, which gave birth to our A.B.C. Islands, the formations were put into an oblique position. The formations are cut off more or less horizontally and consist of alternating solid and soft layers. The "rooien" are running parallel in the softer layers, till they cut through the entire formation somewhere via a transverse "rooi".

The Netherlands is particularly rich in different kinds of rock, too, and in this respect just as interesting to a geologist as to an amateur. Rivers carried along the most different rock fragments to our country and the land ice transported large quantities of foreign rocks from Scandinavia. As a result of the rapid weathering it is rather difficult to find a diabase or a tuff in our own country. By recrystallisation of the original minerals, the erratic blocks in our country often have a greenish colour and are more granular. Besides, they are difficult to distinguish from other kinds of rock.

In some preceding chapters we already discussed not only that these rocks were folded, but also that new materials penetrated into the folded formations. Now this penetrating magma cooled already deep in the earth's crust.

This cooling of a mobile magma to a firm and solid rock took a long time. Some minerals crystallized soon and formed a sediment in the fluid magma, other minerals crystallized later and managed to penetrate higher up into the folded formations. To these earlier crystallized magmatic rocks belong those of the Hooiberg in Aruba. It is a magnificent dark-coloured rock, in which we can clearly distinguish the crystals which grew much more slowly and which are about 1 cm across.

The peculiar structure and composition made these rocks of the Hooiberg very rare all the world over.

To the later crystallization products of the mobile magma belongs the diorite of Aruba. To the naked eye it looks much like the curbstones of granite so often used in Holland, a kind of rock related to the diorite of Aruba.

The fact that the diorite crystallized at a later date than the rocks of the Hooiberg, often shows up clearly, for instance at the base of the Hooiberg.

For here we can see how the young light-blue dioritic materials have penetrated into fissures and fractures of the rocks of the Hooiberg, which were at that time already solidified.

The latest products of the coagulating magma are the quartz veins of Aruba and a few copper veins of Curaçao. On "Seroe Kristal", the name speaks for itself, you can find beautiful clear, hexagonal quartz crystals of such a vein.

A "Seroe" J. BONKE.

The penetration of the magma body had another result, too: the older lavas and tuffs, remaining unchanged in Curaçao and Bonaire, were as it were "re-baked" at high temperature and pressure to firm crystalline rocks. Several "Seroes" on Aruba consist of such re-crystallized metamorphic rock.

That these rocks occur precisely in Aruba is a result of the gigantic elevation of the Island. The erosion of the emerged parts finally denuded these products which already cooled and coagulated at a depth of several kilometres. Curaçao and Bonaire were elevated less highly and there we find a diorite vein only occasionally where these rocks could come up through a fissure far away from the original magma seat.

The A.B.C. Islands have passed through a very eventful geological history. Various sediments, for instance, were deposited during the several submersion periods on top of the older ones. To mention some of them: conglomerate, sandstone, clay, limestone and marl. A conglomerate is cemented gravel and very easy to recognize.

Sand and clay are well-known in the Netherlands, too! Limestone and marl (a mixture of lime and clay) are sometimes more difficult to recognize.

That is the reason why a geologist always has a small bottle of hydrochloric acid at hand. The reaction of limestone with hydrochloric acid facilitates recognition. To the collector of fossils, (petrified organisms) limestone and marl formations are the right places to look for them.

Limestone and marl were deposited under circumstances when the supply of coarse materials, as sand and gravel, was impossible. As a result, the fossils are often well preserved.

As a fine example I would like to mention: the surroundings of "Butucoe" in Aruba, "Seroe di Cueba" in Curaçao and those of "Porta Spanjo" in Bonaire. Sometimes the limestone consists entirely of the remains of tiny one-celled organisms, which lived in the sea millions of years ago and of which the small skeletons sank to the seabottom.

Speaking about the "Seroe di Cueba" in Curaçao, it is well to stress the fact how flat the top of this hill is. Two other "seroes" in the immediate vicinity have such completely flat tops, too.

All these flat tops have resulted from one special sea-level, and the incisions which were afterwards made by "rooien" divided the original plane into three separated "seroes". So the action of the waves, too, played an important part in the formation of the hills as we know them at present.

Finally there are "seroes" which owe their existence to conditions other than those dealt with above.

During the last emergence of the Islands above the level of the sea, coral-reefs were growing along the coasts. In this way the limestone caps on top of the earlier formations were formed.

Dissolution by the action of rainwater is the most important way of erosion of the limestones. But this dissolving process proceeds very slowly, much more slowly for instance than the erosion of the old volcanic rocks lying under these reef limestones.

In this way "seroes", such as "Ronde Klip" and "Tafelberg Hieronymus" in Curaçao, were formed. The slow disintegration of the flat limestone tops of these "seroes" protected the underlying diabase against erosion.

Climbing such "seroes" we walk up the hill from the flat and low diabase scenery, via a steep diabase slope, to the rather thin limestone cap, about twelve metres thick and lying on top.

In several places we can clearly distinguish the corals in the elevated reef limestone.

Yet in the limestone of "Ronde Klip" and "Tafelberg Hieronymus" you will look for corals in vain. This limestone has resulted from natural cementing of limesand dunes!

At that time the surf ground the corals to sand, and this sand, blown up to dunes, was cemented to limestone by rainwater.

In Holland such limesand does not occur of course. For the extensive reef growth along the coast, the source of limesand, is only found in tropical regions.

Finally something must be said about the "rooien".

On Aruba "rooien" are found cutting through gold veins containing quartz layers. Of course the rainwater will carry off the light materials faster than the heavy ones, and when the strength of the current diminishes the heaviest erosion products will be deposited first. The specific gravity of gold is high, therefore it is possible to find a nugget of gold in the gully of such a "rooi".

So it could happen that a little boy found a nugget of gold weighing a few dozen grammes.

But it is no use coming to the Islands with the intension of hunting for gold! It is much more valuable to have an open eye for living nature, which in this case certainly includes the earth's crust.